CLAIMS

WHAT IS CLAIMED IS:

1. An apparatus for drilling a borehole and determining a parameter of interest of a formation surrounding the borehole, said apparatus comprising:

   (a) a longitudinal member for rotating a drill bit and adapted to be conveyed in the borehole;

   (b) a nuclear magnetic resonance (NMR) sensor assembly including at least one member slidably coupled to and spaced apart from said longitudinal member defining a flow path for drilling fluid therebetween, said NMR sensor assembly producing a pulsed RF field for obtaining measurements indicative of the parameter of interest of the formation, said RF field characterized by a plurality of parameters; and

   (c) a downhole processor for varying at least one parameter of the pulsed RF field.

2. The apparatus of claim 1 wherein the pulsed RF field comprises a pulse sequence of the form:

$$\left[TW_i - 90_{\pm\pi/2} - (\tau - X - \tau - echo)_j\right]_i$$

wherein TW is a wait time, $90_{\pm\pi/2}$ refers to a phase alternated 90^0 tipping pulse , X is a refocusing pulse with a tipping angle that lies between 90^0 and 180^0, j is the number of echos observed, i is a number of repetitions, and 2τ is an interecho

spacing, and wherein the parameter of interest of the pulsed RF field is selected from the group consisting of: (i) the tipping angle of the refocusing pulse, (ii) the number of echos j, (iii) the number of repetitions i, (iv) the interecho spacing, and (v) the wait time.

3. The apparatus of claim 1 wherein the sensor assembly further comprises:

at least one clamping device for engaging the borehole to clamp the at least one member to the borehole.

4. The apparatus of claim 1 wherein the longitudinal member is a segment of drill pipe.

5. The apparatus of claim 1 wherein the longitudinal member is a shaft on a downhole directional drilling assembly.

6. The apparatus of claim 1 further comprising:

at least one thruster connected to the sensor assembly for providing axial decoupling of the at least one member of the sensor assembly from the longitudinal member and for dampening vibrations to the at least one member.

7. The apparatus of claim 1 wherein the NMR sensor assembly is operated in one of (i) a clamped mode, (ii) a rotating mode, (iii) in a changing mode, and, (iv) a tripping mode.

8. The apparatus of claim 1 further comprising a drilling sensor module for making measurements relating to a drilling parameter selected from the group consisting of (i) a bit bounce, (ii) stick-slip of the longitudinal member, (iii) backward rotation, (iv) torque, (v) shocks, (vi) borehole and annulus pressure, and (vii) acceleration.

9. The apparatus of claim 1 further comprising a formation evaluation sensor for making measurements indicative of at least one of (i) a lithology of the formation, and, (ii) a fluid content of the formation.

10. The apparatus of claim 1 further comprising a telemetry module for communicating signals to and from a surface location.

11. The apparatus of claim 1 wherein the processor provides a quality control (QC) diagnostic based on at least one of (i) a signal from a motion sensor, (iii) a sum of echos (SE) produced by the NMR sensor assembly.

12. The apparatus of claim 11 wherein the processor uses said QC diagnostic for at least one of (i) discarding a subset of said measurements, (ii) replacing a subset of said measurements with another subset of said measurements, (iii) zeroing out partial echo trains.

13. The apparatus of claim 1 wherein the processor performs an averaging of measurements within a time window.

14. The apparatus of claim 13 wherein the averaging is one of (i) an unweighted averaging, and, (ii) a weighted averaging.

15. The apparatus of claim 1 wherein the processor combines data with different phases of the tipping pulse for reducing an error in the measurements.

16. The apparatus of claim 1 wherein the processor applies a stimulated echo correction to said measurements.

17. The apparatus of claim 16 wherein said stimulated echo correction is determined by at least one of (i) a temperature of the formation, (ii) an intensity of the RF field, (iii) a bandwidth of the tipping pulse, and, (iv) a bandwidth of the refocusing pulse.

18. The apparatus of claim 1 wherein said measurements further comprise two channels of data, the processor further determining a corrected measurement based on measurements on said two channels and a phase angle therebetween.

19. The apparatus of claim 1 wherein the processor applies a calibration to said measurements, said calibration based upon measurements made with the NMR sensor assembly in a medium of known porosity.

20. The apparatus of claim 19 wherein said calibration is dependent upon a temperature of the medium.

21. The apparatus of claim 1 wherein the processor applies a correction for salinity of a fluid in the formation.

22. The apparatus of claim 2 wherein the processor stacks data acquired in a plurality of repetitions.

23. The apparatus of claim 1 wherein the processor applies a multiexponential fit to said measurements.

24. The apparatus of claim 1 wherein the processor applies a correction based upon a temperature of the formation to said measurements.

25. The apparatus of claim 10 wherein the processor varies the at least one parameter of the pulsed RF field at least partially in response to a control signal from the surface location.

26. The apparatus of claim 9 wherein the processor further comprises an expert system for determining from said measurements of the formation evaluation sensor at least one of (A) the lithology of the formation, and, (ii) the fluid content of the formation.

28. The apparatus of claim 26 wherein the processor varies the at least one parameter of the pulsed RF field at least partially in response to the at least one of (A) the determined lithology of the formation, and, (B) the determined fluid content of the formation.

29. The apparatus of claim 28 wherein the pulsed RF field comprises a pulse sequence of the form:

$$\left[TW_i - 90_{\pm\pi/2} - (\tau - X - \tau - echo)_j\right]_i$$

wherein TW is a wait time, $90_{\pm\pi/2}$ refers to a phase alternated 90^0 tipping pulse , X is a refocusing pulse with a tipping angle that lies between 90^0 and 180^0, j is the number of echos observed, i is a number of repetitions, and 2τ is an interecho spacing, and wherein the parameter of interest of the pulsed RF field is selected

from the group consisting of: (I) the tipping angle of the refocusing pulse, (II) the number of echos j, (III) the number of repetitions i, (IV) the interecho spacing, and, (V) the wait time.

30. The apparatus of claim 1 wherein the NMR sensor assembly is operated in a clamped mode and the processor varies the at least one parameter in response to a rate of penetration (ROP) of the drillbit.

31. The apparatus of claim 1 wherein the NMR sensor assembly is operated in one of (i) a rotating mode, (ii) a changing mode, and, (iii) a tripping mode, and the processor varies the at least one parameter in response to a signal from a motion sensor on the apparatus.

32. The apparatus of claim 31 wherein the NMR sensor assembly is operated in a tripping mode and the processor further applies a correction to said measurements based upon a signal from a motion sensor on the apparatus.

33. The apparatus of claim 31 wherein the processor processes said measurements in one of (i) based upon a signal from a surface processor, and, (ii) independently of the surface processor.

34. The apparatus of claim 1 wherein the processor performs at least one of (i) deleting a subset of said measurements, (ii) replacing a subset of said measurements, and, (iii) zeroing a subset of echos in an echo train.

35. The apparatus of claim 1 wherein the processor determines a calibration factor relating said measurements to a porosity of the formation, said calibration factor being related to a temperature of the formation,

36. The apparatus cf claim 1 wherein the processor determines from said measurements the parameter of interest, said parameter of interest being at least one of (i) a total porosity, (ii) an effective porosity, (iii) a volume fraction of clay bound water, and, (iii) and a volume fraction of bound water irreducible.

37. An apparatus for drilling a borehole and determining a parameter of interest of a formation surrounding the borehole, said apparatus comprising:

(a) a longitudinal member for rotating a drill bit and adapted to be conveyed in the borehole;

(b) a nuclear magnetic resonance (NMR) sensor assembly producing a pulsed RF field for obtaining measurements indicative of the parameter of interest of the formation, said RF field characterized by a plurality of parameters; and

(c) a downhole processor including an expert system for controlling at least one parameter of the pulsed RF field.

38. The apparatus of claim 37 wherein the pulsed RF field comprises a pulse sequence of the form:

$$\left[TW_i - 90_{\pm\pi/2} - (\tau - X - \tau - echo)_j\right]_i$$

wherein TW is a wait time, $90_{\pm\pi/2}$ refers to a phase alternated 90^0 tipping pulse , X is a refocusing pulse with a tipping angle that lies between 90^0 and 180^0, j is the number of echos observed, i is a number of repetitions, and 2τ is an interecho spacing, and wherein the parameter of interest of the pulsed RF field is selected from the group consisting of: (i) the tipping angle of the refocusing pulse, (ii) the number of echos j, (iii) the number of repetitions i, (iv) the interecho spacing, and (v) the wait time.

39. The apparatus of claim 37 wherein the NMR sensor assembly further comprises:

(i) a member slidably coupled to and spaced apart from said longitudinal member defining a flow path for drilling fluid therebetween; and

(ii) at least one clamping device for engaging the borehole to clamp said member to the borehole.

40. The apparatus of claim 37 wherein the longitudinal member selected from the group consisting of (i) a segment of drill pipe, and, (ii) a shaft on a downhole directional drilling assembly.

41. The apparatus of claim 37 further comprising a telemetry module for communicating signals to and from a surface location

42. The apparatus of claim 38 wherein the processor applies a stimulated echo correction to said measurements, said stimulated echo correction determined by at least one of (i) a temperature of the formation, (ii) an intensity of the RF field, (iii) a bandwidtn of the tipping pulse, and, (iv) a bandwidth of the refocusing pulse.

43. The apparatus of claim 37 further comprising a formation evaluation sensor for making measurements indicative of at least one of (i) a lithology of the formation, and, (ii) a fluid content of the formation.

44. The apparatus of claim 43 further comprising using the expert system for determining from said measurements of the formation evaluation sensor at least one of (A) the lithology of the formation, and, (ii) the fluid content of the formation.

45. A method of using a bottom hole assembly (BHA) conveyed in a borehole of an earth formation for determining a parameter of interest of the formation comprising:

(a) using a longitudinal member on the BHA for penetrating the formation;

(b) using a nuclear magnetic resonance (NMR) sensor assembly on the BHA for producing a pulsed RF field for obtaining measurements indicative of the parameter of interest of the formation, said RF field characterized by a plurality of parameters, said NMR assembly including at least one member slidably coupled to and spaced apart from said longitudinal member defining a flow path for drilling fluid therebetween; and

(c) using a downhole processor on the BHA for varying at least one parameter of the pulsed RF field.

46. The method of claim 45 wherein producing the pulsed RF field comprises pulsing a transmitter on the sensor assembly with a pulse sequence of the form:

$$\left[TW_i - 90_{\pm\pi/2} - (\tau - X - \tau - echo)_j\right]_i$$

wherein TW is a wait time, $90_{\pm\pi/2}$ refers to a phase alternated 90^0 tipping pulse , X is a refocusing pulse with a tipping angle that lies between 90^0 and 180^0, j is the number of echos observed, i is a number of repetitions, and 2τ is an interecho spacing, and wherein the parameter of interest of the pulsed RF field is selected from the group consisting of: (i) the tipping angle of the refocusing pulse, (ii) the number of echos j, (iii) the number of repetitions i, (iv) the interecho spacing, and (v) the wait time.

47. The method of claim 45 further comprising using at least one clamping device for engaging the borehole to clamp the at least one member to the borehole.

48. The method of claim 45 further comprising using at least one thruster connected to the sensor assembly for providing axial decoupling of the at least one member of the sensor assembly from the longitudinal member and for dampening vibrations to the at least one member.

49. The method of claim 45 further comprising using a drilling sensor module for making measurements relating to a drilling parameter selected from the group consisting of (i) a bit bounce, (ii) stick-slip of the longitudinal member, (iii) backward rotation, (iv) torque, (v) shocks, (vi) borehole and annulus pressure, and (vii) acceleration.

50. The method of claim 45 further comprising using a formation evaluation sensor for making measurements indicative of at least one of (i) a lithology of the formation, and, (ii) a fluid content of the formation.

51. The method of claim 45 further comprising using a telemetry module on the BHA for communicating signals to and from a surface location.

52. The method of claim 45 further comprising using the processor for providing a quality control (QC) diagnostic based on at least one of (i) a signal from a motion sensor, (iii) a sum of echos (SE) produced by the NMR sensor assembly.

53. The method of claim 52 further comprising using the processor, based on said QC diagnostic, for at least one of (i) discarding a subset of said measurements, (ii) replacing a subset of said measurements with another subset of said measurements, (iii) zeroing out partial echo trains

54. The method of claim 45 further comprising using the processor for combining measurements with different phases of the tipping pulse for reducing an error therein.

55. The method of claim 45 further comprising using the processor for applying a stimulated echo correction to said measurements.

56. The method of claim 45 wherein said measurements further comprise two channels of data, the method further comprising using the processor for determining a corrected measurement based on measurements on said two channels and a phase angle therebetween.

57. The method of claim 45 further comprising using the processor for calibrating said measurements, said calibration based upon measurements made with the NMR sensor assembly in a medium of known porosity.

58. The method of claim 45 further comprising using the processor for applying a multiexponential fit to said measurements.

59. The method of claim 51 further comprising sending a control signal from the surface location to the processor and varying the at least one parameter of the pulsed RF field in response thereto.

60. The method of claim 50 wherein the processor further comprises an expert system for determining from said measurements of the formation evaluation sensor at least one of (A) the lithology of the formation, and, (ii) the fluid content of the formation.

61. The method of claim 60 wherein the expert system varies the at least one parameter of the pulsed RF field at least partially in response to one (A) the lithology of the formation, and, (ii) the fluid content of the formation.

62. The method of claim 45 further comprising:

(i) operating the NMR sensor assembly in a clamped mode,

(ii) determining a rate of penetration of the longitudinal member, and

(iii) varying the at least one parameter of the RF field in response to said rate of penetration (ROP) of the drillbit.

63. The method of claim 45 further comprising using the processor for determining from said measurements the parameter of interest, said parameter of interest being at least one of (i) a total porosity, (ii) an effective porosity, (iii) a volume fraction of clay bound water, and, (iii) and a volume fraction of bound water irreducible.

64. A method of using a bottom hole assembly (BHA) conveyed in a borehole of an earth formation for determining a parameter of interest of the formation comprising:

(a) using a longitudinal member on the BHA for penetrating the formation;

(b) using a nuclear magnetic resonance (NMR) sensor assembly on the BHA for producing a pulsed RF field for obtaining measurements indicative of the parameter of interest of the formation, said RF field characterized by a plurality of parameters; and

(c) using a downhole processor including an expert system for determining a lithology of the formation and selecting at least one parameter of the pulsed RF field based at least in part on the determined lithology.

65. The method of claim 64 wherein producing the pulsed RF field comprises pulsing a transmitter on the sensor assembly with a pulse sequence of the form:

$$\left[TW_i - 90_{\pm\pi/2} - (\tau - X - \tau - echo)_j\right]_i$$

wherein TW is a wait time, $90_{\pm\pi/2}$ refers to a phase alternated 90^0 tipping pulse , X is a refocusing pulse with a tipping angle that lies between 90^0 and 180^0, j is the number of echos observed, i is a number of repetitions, and 2τ is an interecho spacing, and wherein the parameter of interest of the pulsed RF field is selected from the group consisting of: (i) the tipping angle of the refocusing pulse, (ii) the number of echos j, (iii) the number of repetitions i, (iv) the interecho spacing, and (v) the wait time.

66. The method of claim 64 further comprises:

(i) using a member on the NMR assembly slidably coupled to and spaced apart frcm said longitudinal member defining a flow path for drilling fluid therebetween; and

(ii) using at least one clamping device for engaging the borehole to clamp said member to the borehole.

67. The method of claim 64 wherein the longitudinal member is selected from the group consisting of (i) a segment of drill pipe, and, (ii) a shaft on a downhole directional drilling assembly.

68. The method of claim 64 further comprising using a telemetry module on the BHA for communicating signals to and from a surface location.

69. The method of claim 65 further comprising using the processor for applying a stimulated echo correction to said measurements, said stimulated echo correction determined by at least one of (i) a temperature of the formation, (ii) an intensity of the RF field, (iii) a bandwidth of the tipping pulse, and, (iv) a bandwidth of the refocusing pulse.

70. The apparatus of claim 64 further comprising a formation evaluation sensor for making measurements indicative of at least one of (i) a lithology of the formation, and, (ii) a fluid content of the formation.

71. The apparatus of claim 70 further comprising using the expert system for determining from said measurements of the formation evaluation sensor at least one of (A) the lithology of the formation, and, (ii) the fluid content of the formation.

72. A method of using a bottom hole assembly (BHA) conveyed in a borehole of an earth formation for determining a parameter of interest of the formation comprising:

(a) using a longitudinal member on the BHA for penetrating the formation;

(b) using a nuclear magnetic resonance (NMR) sensor assembly on the BHA for producing a pulsed RF field for obtaining measurements indicative of the parameter of interest of the formation, said RF field characterized by a plurality of parameters; and

(c) using a downhole processor and for selecting at least one parameter of the pulsed RF field at least partially in response to a control signal sent to the processor from a surface location.